Mapping buried metallic objects and titaniferous placers in the Mississippi Sound, Gulf of Mexico

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ABSTRACT

Recent experiments with a marine induced polarization (IP) streamer system have shown that it can find and map titaniferous placers on and beneath the sea floor (Wynn and Laurent, 1998) and facies changes in the substrate beneath sandy shoals (Wynn and others, 1998). Close examination of profile data acquired in the Mississippi Sound, however, shows that the system can also detect certain conductive, polarizing objects that are buried beneath the sea floor and not discernible with conventional bathymetry. The streamer system is designed to detect polarizeable materials down to at least 6 meters below the sediment-water interface. The recent data show broad phase-shift (IP) anomalies along the east side of Cat Island, off the coast of Biloxi, MS. Dark, titaniferous sands can be seen in dissected benches and berms on the island's coastline, reinforcing the conclusion that the IP system is mapping the ilmenite-rich ($FeTiO_3$) sediments reported in shoals there (Foxworth, 1962). Interspersed in these data, however, are several narrow electrical anomalies of two kinds: resistivity, and resistivity-IP anomalies. Both kinds show pronounced drops in the already-low resistivity, and several of these also have coincident phase-shift anomalies. The polarizing objects observed are ~10 to 20 meters across, but the IP anomalies can be seen ~ 20 to 40 meters laterally from their centers. The sources of these anomalies are probably man-made in origin, buried under a veneer of modern sediments. We speculate that these are shipwrecks, sunken buoys or parts thereof, lost and later buried (in water now about 3 meters deep) by Hurricane Camille, which passed through the area in 1969. We cannot, however, preclude emplacement and burial at an earlier time.

BACKGROUND

The Exclusive Economic Zone (EEZ), extends from 3 nautical miles (5.6 km) off the coast of the United States and its affiliated islands out to 200 nautical miles (321 km). More than 3 million square miles (nearly 8 million square kilometers) of territory that belongs to the United States is underwater and therefor relatively unknown (Lockwood and McGregor, 1988). Studies suggest that the EEZ contains substantial mineral resources, including industrial minerals such as ilmenite (a source of titanium), and gold and platinum are frequently associated with these minerals in some places (Wynn, 1988; Wynn and others, 1990).

The EEZ also contains vast amounts of urban waste that have been dumped offshore (Bothner and others, 1995). On land, these materials have been shown to give rise to substantial IP effects on the order of 10-30 PFE (Percent Frequency Effect; see Angoran and others, 1974). Examples of waste dumped offshore (both sewage and garbage) can be found in the Atlantic continental shelf east of Miami, FL, in the New York Bight, in Long Island Sound, and in Boston Harbor, among other places. These sea floor waste deposits are significant health and even navigation hazards, and they are moving under the influence of ocean currents. There is evidence that garbage and other man-made waste can not only be transported, but also easily buried by sediments under the influence of ocean currents whose speeds often exceed several knots. During the huge storm surges associated with hurricanes, the sediment-redistribution process can be accelerated dramatically; during hurricane Camille, which passed through the Gulfport-Biloxi area of Mississippi in 1969, entire islands disappeared, were reformed, or were moved (Bob Woolsey, Mississippi Mineral Resources Institute, University, MS, oral comm., 1998).

In addition to urban waste dumps, there are numerous places in the EEZ where unexploded ordnance (UXO) remains from World War II and peacetime military exercises. This UXO can be buried beneath a shallow layer of sediments and is invisible. It poses a threat to divers, marine life, and fishermen.

Several approaches have been taken to characterize and map the mineral resources and hazards of the EEZ. Side-scan sonar and high-frequency seismic-reflection ("chirp") methods can be used to identify shapes and features on the sea floor. Marine scientists have learned to correlate characteristic signatures from these data with ancient beach deposits and, in places, with modern dump sites. Sonar images, however, can identify only shapes, and then only on a relatively large scale. The images cannot directly identify mineral deposits or UXO.

Grab-sampling and vibracoring can sample the sea floor and the shallow sediments beneath it, but both techniques provide only point data, are labor intensive, and are very expensive. It became apparent that a new method was needed to (1) map large tracts of bottom sediments down to at least 20 feet (6 meters) below the sea floor (the typical depth limit of a vibracore), and (2) directly detect and hopefully differentiate minerals and metals down to small concentrations. We have conducted experiments using the induced-polarization (IP) method to map the shallow sea floor at a number of sites in the Atlantic Ocean and Gulf of Mexico. IP resistivity and phase data together provide a great deal of new, high-resolution (~1 meter spacing) data that can compliment seismic surveys of the near-shore sea floor.

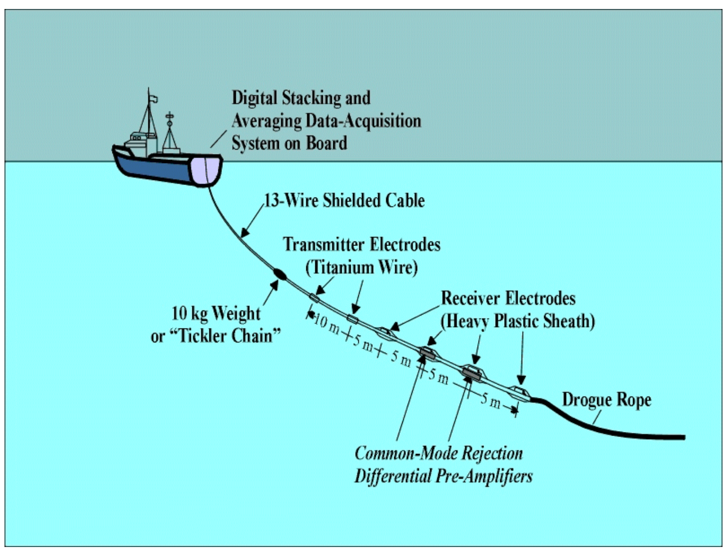

Figure 1. ***A schematic representation of a dual-depth receiver dipole marine IP streamer. Between 2 and 5 amps of current are injected into the sediments through the titanium-wire electrodes***

Laboratory and field experiments carried out in the 1980's (Wynn and others, 1990) showed that the IP method on land was extremely sensitive to certain titanium-bearing and thorium-bearing industrial minerals such as ilmenite and monazite, respectively. The strength of the measured IP responses were unprecedented, sometimes more than 5 times greater than values measured for an equivalent amount of pyrite with the same grain-size. Thorium- and titanium-bearing minerals are generally found in crystalline rocks, but are almost always economically mined from ancient beach deposits where they have been deposited after weathering and river transport.

Initial land-based IP experiments with placer sands led to the development of a streamer system that could be used to measure the IP effect in sea floor sediments. This type of marine IP streamer system was towed behind a ship offshore of Savannah, Georgia, and St. Petersburg , Florida, and gave promising results (Wynn and Laurent, 1998; the streamer is schematically represented in figure 1).

The present version of this streamer system incorporates an encryption-key GPS system downloading location data (latitude, longitude, speed-over-ground (SOG), and heading (COG) information) once every two seconds to a laptop computer. Simultaneously, resistivity and phase-shift data (a measure of the IP effect) are acquired and processed in real-time for two different dipole-spacings (in other words, sampling two different depth-intervals) on the towed streamer, and all these data are downloaded to the laptop computer in 1-second increments. The result is the simultaneous acquisition of resistivity and IP information for two different depths: roughly 0 to 2 meters, and 2 to 6+ meters below the sea floor. With the EK-GPS information, we can recover precise locations of any anomalies or "hits" encountered during profiling, with estimated precision to within 5 - 10 meters. By towing the streamer back-and-forth in a "lawnmower" fashion we can thus survey large areas of the sea floor and look for line-to-line correlations. In order to inject sufficient signal into the sediments, the streamer must be towed in direct contact with the sea floor.

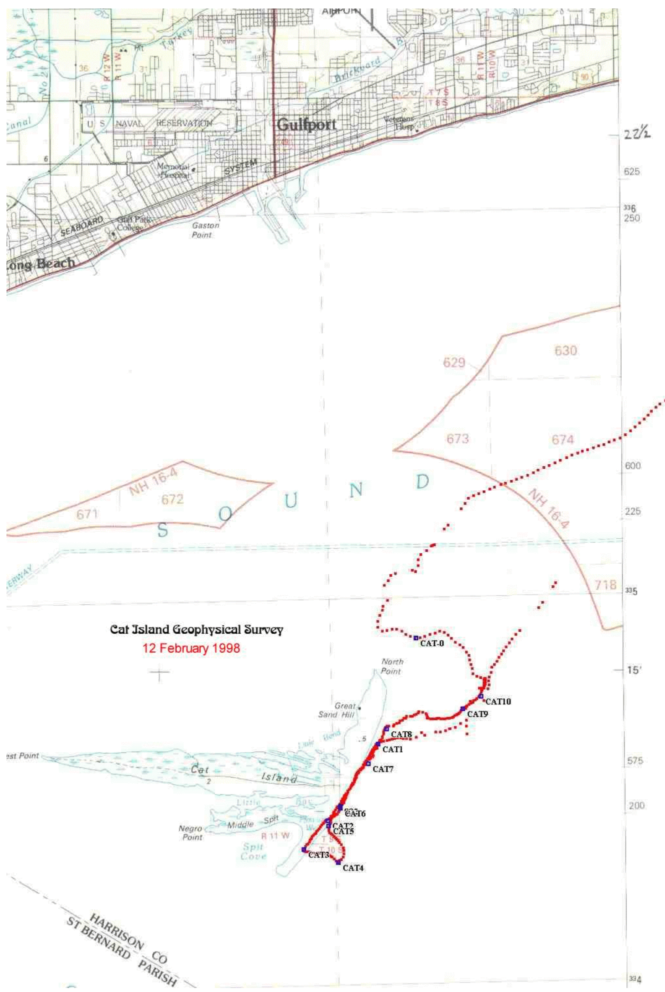

Figure 2. ***The track of the R/V Kit Jones towing the marine IP streamer along the east margin of Cat Island, Mississippi Sound, Gulf of Mexico.***

THE CAT ISLAND SURVEY

A fourth test of the marine IP streamer system was conducted off the eastern shore of Cat Island, in the Mississippi Sound of the Gulf of Mexico (see map, figure 2). Substantial accumulations of heavy placer sands including ilmenite are visible even from ships trolling offshore of Cat Island. Two close-inshore parallel passes were made towing the streamer to test for the presence of ilmenite, and at the end of the first (south-going) pass we moved the ship well offshore to contrast the response of the ilmenite sands to carbonate muds (this "mud-test" is at waypoint "CAT4" on figures 2 and 4). Figure 3 is a 3-D representation of the data showing the IP anomalies and their position on the map. The shallow-penetrating data are represented in the upper two colored curves; the deeper-penetrating data in the next two curves, and the actual vessel track is represented as a black line along the eastern face of Cat Island. Note that the deeper-penetrating dipole appears attenuated with respect to the shallow dipole; this is apparently due to the increased impedance of a failing #4 receiver electrode. Note also that the south-going pass phase-shift signal (the green line) doesn't overlay exactly the north-going part of the signal. This is because these data have not been shifted horizontally by the 135-meter separation between the GPS antenna (located on the ship itself), and the active part of the streamer towed behind the ship. The separation netween the two (south-going vs. north-going) peaks is exactly 270 meters, providing a satisfying spatial repeatability test.

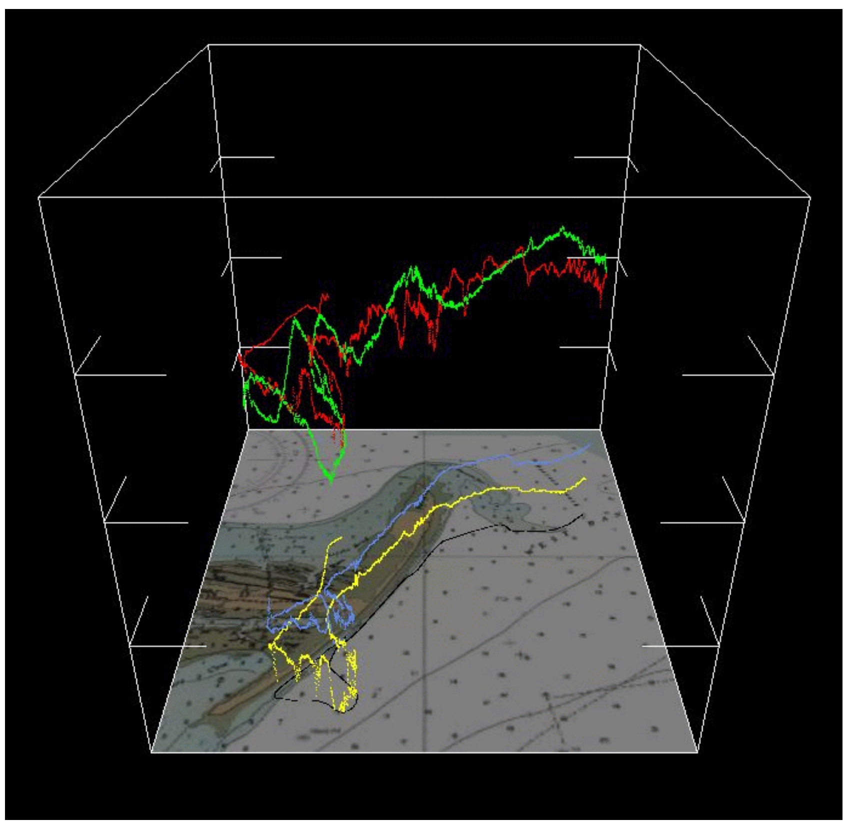

Figure 3. ***A 3-D representation of the towed-streamer IP data with respect to the eastern edge of Cat Island. The IP phase-shift for the shallow dipole is green, and the resistivity data is shown in red. The deeper dipole phase-shift is blue and the corresponding resistivity is yellow. The ship's track is the black line along the eastern edge of the island.***

Figure 4 shows an expanded version of the south-going profile, for the shallow-penetrating dipole only. In this figure we can see the IP effect of ilmenite in tidal deltas (the first increase and decrease in phase-shift on the left). In a test of the IP system we moved the ship out away from Cat Island into carbonate muds (which do not have an IP effect), and the IP response decreased dramatically (figure 4, the bottom of the second "V" around 2,200 meters). Just before turning to start the outward-bound leg at waypoint CAT3, we observed an interesting relatively high-frequency "blip" in both the resistivity and the phase-shift data (figures 4 and 5, at about 1,200 meters). This phase-shift increase, coincident with a local resistivity low, suggests a buried metallic object of some sort. This event is shown expanded in figure 5. The object, whatever it is, is completely buried in the sediments because it was not seen in the bathymetry as we passed over it. It is at least 10 meters wide where the profile crossed it. One possible explanation for this sort of anomaly is the presence of a buried chunk of metallic debris beneath the sediments. While the width of the anomaly suggests the object is only about 10 meters wide where crossed, it's interesting to note that the IP anomaly is so strong that it is detected at least 20 meters away laterally from the source. Note also an apparent asymmetry, which may imply a metallic object dipping down-range. The streamer was designed using computer modeling to sample only about 6 meters deep into the underlying sediments, but this broad anomaly implies that polarizing bodies can be detected much deeper for the 10-meter dipole-spacing we used, perhaps up to 15+ meters below the water-sediment interface. Note in these figures that a *differential* resistivity is being plotted, e.g., the resistivity minus a fixed constant value of 0.47 ohm-meters, in order to expand the visible dynamic range of subtle resistivity variations. This gives rise to apparent negative numbers, but the actual resistivities remain positive.

Figure 6 shows the north-going marine IP profile. When shifted horizontally to geometrically correct for the 135 meter separation between the active part of the towed streamer and the location of the GPS antenna on the ship, the north-going profile and the south-going profile almost exactly mirror each other. In figures 3, 4, and 6 the shallow dipole data show an irregular, cusp-like response suggesting that the ilmenite sands are distributed in a cyclic, wave-like manner along the face of Cat Island. Note in these figures that the resistivity variations have been amplified by removal of a constant. This increases the viewable dynamic range in the plot representation and allows us to see subtle variations in the sea floor porosity. The cusp-shaped phase-shift anomalies appear to be due to tidal deltas loaded with ilmenite just offshore of Cat Island.

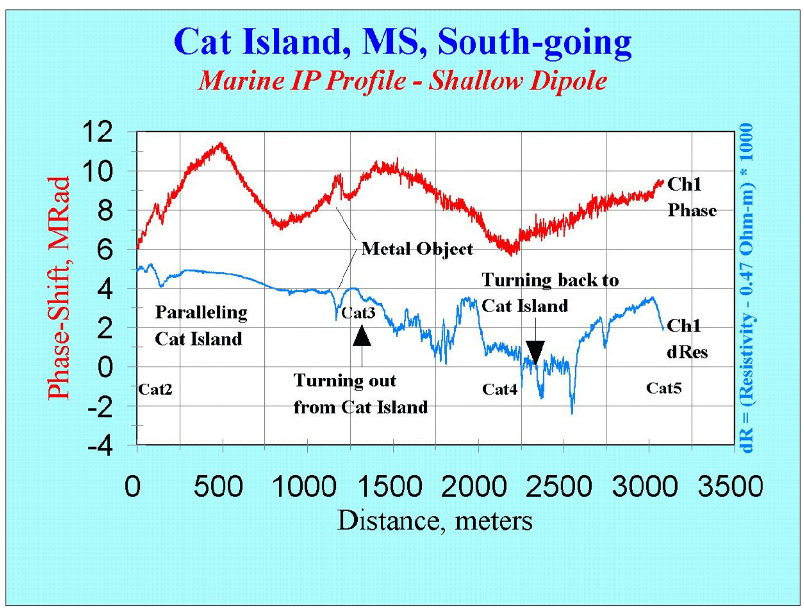

Figure 4. ***The marine IP data acquired off the east coast of Cat Island (south-going run), showing the intermittent nature of the polarizing materials believed to be ilmenite-bearing heavy placer sands. Note the apparent buried metallic object around 1,170 m.***

Note on the north-going profile that there are also a number of additional conductor-polarizer "blips", notably at 2,750 m, 3,050 m, 3,980 m, and 5,100 meters. Three of these have coincident phase-shift anomalies, but the one at 3,050 m does not. The feature at 3,980 m can be seen expanded in figure 7; it is broader and muted than the anomaly represented in figure 4. This suggests that the object at 3,980 m is more deeply buried than the object encountered at 1,170 m on the south-going profile. Figure 8 shows the one resistivity anomaly (at 3,050 m) that did NOT have a coincident induced polarization (phase-shift) anomaly. The bottom of this resistivity low is also clearly truncated. A possible interpretation is that we are seeing a dredged trench that has been refilled with more recent, slightly higher-porosity and less-consolidated sediments, probably dumped there during the Hurricane Camille event.

CONCLUSIONS

On land, electrodes must be dug or pounded into the ground to make IP measurements. At sea, one simply uses titanium wire wrapped around the streamer, and seawater conductivity serves to complete the return path for the transmitted current. This use of seawater instead of planted electrodes has the serendipitous effect of suddenly making IP measurements highly mobile-- we can now theoretically make more IP measurements at sea in a week than have been made by geophysicists on land-- worldwide-- for the past 50 years!

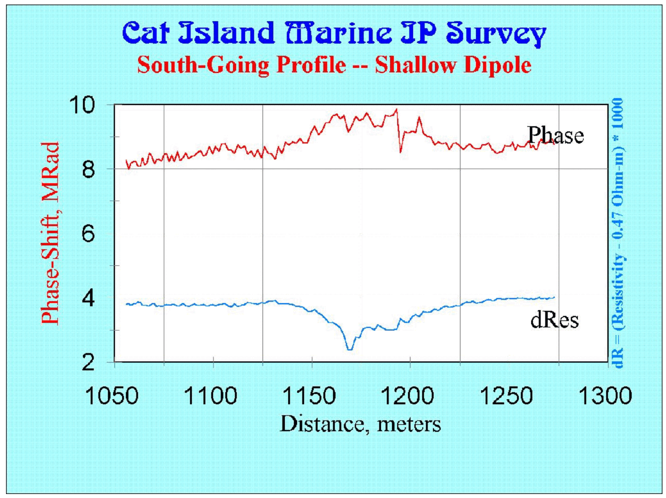

Figure 5. ***Expanded image of the buried conductive polarizer on the south-going profile, Cat Island marine IP survey.***

Experiments with this rapid profiling system at Cat Island in the Mississippi Sound show that we can map titanium-rich placer materials such as ilmenite (and therefor any associated zircon, gold, or other heavy placer minerals) at a three-knot towing speed. A surprise by-product of this survey was evidence of a number of buried polarizing objects that are also more conductive than the surrounding salt-water-saturated sediments. A possible interpretation for these anomalies is that they represent buried man-made metallic objects - wrecks or sunken buoys - lost during the destructive events associated with Hurricane Camille in 1969.

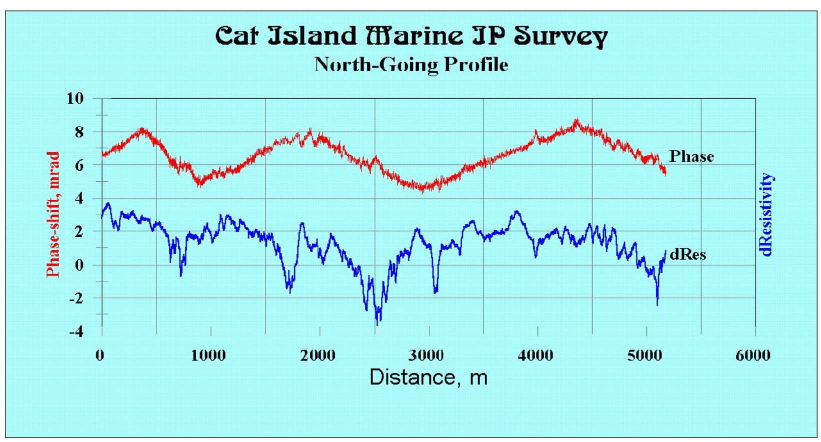

Figure 6. ***The north-going marine IP profile off of Cat Island, Mississippi Sound.***

A third type of anomaly - conductors without an associated polarization anomaly - are likely caused by re-filled dredge trenches. More recent sediments will most likely have a higher porosity than the original underlying material the trench is cut into, giving rise to a relative resistivity low but with no polarization anomaly.

These data support the conclusion that a marine IP streamer system (in towed mode) should be able to efficiently and rapidly map (1) heavy placer minerals, (2) unexploded ordnance with metallic components, (3) many shipwrecks, and (4) man-made waste dumped on the sea floor. The current system apparently can detect these materials even if they are buried under a veneer of recent sediments. In the fixed mode (using the multifrequency spectral induced polarization method), the system should also be able to discriminate between the different objects and materials, i.e., roughly characterize them according to their IP signature.

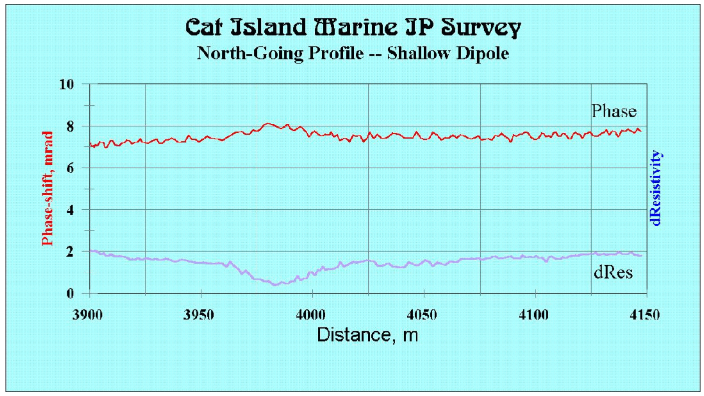

Figure 7. ***Expanded segment of the Cat Island north-going profile, showing an anomaly caused by a deeper conductive, polarizing conductor.***

ACKNOWLEDGMENTS

This work would not have been accomplished without the help and support of numerous individuals and institutions. Jerry Bradley (USGS, Denver) built the streamer pre-amplifiers, and Tom O'Brien (USGS, Woods Hole, MA) helped in the construction of the streamer. Jean Filloux (Scripps Institute of Oceanography, La Jolla, CA) built the highly-stable Ag-AgCl marine receiver electrodes. Bob Woolsey, Jim Petermann, Cathy Grace, Brian Nokes, Ladd Schrantz, and Tom McGee (Mississippi Mineral Resources Institute, University, MS) provided assistance and the use of the R/V Kit Jones for the Cat Island survey.

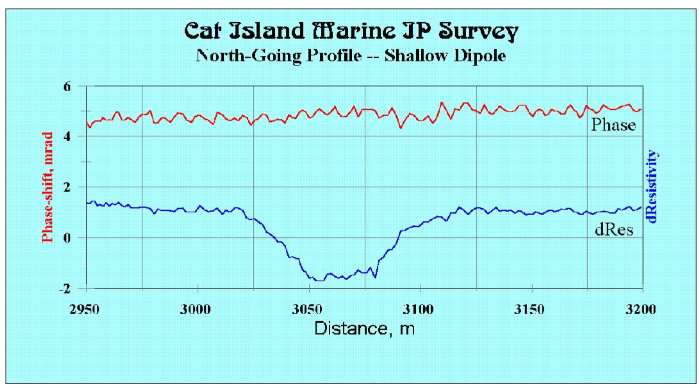

Figure 8. ***A non-polarizing resistivity anomaly; the truncated low implies a trench that has been refilled with higher-porosity, recent sediments.***

REFERENCES

Angoran, Y. E., Fitterman, D. V., and Marshal, D. J., 1974, Induced polarization: a geophysical method for locating cultural metallic refuse: Science, v. 184, p. 1287-1288.

Bothner, M.H., M. Buchholtz ten Brink, and G.E. Ravizza, 1995, Silver and other tracers of sewage particles in coastal and deep sea sediments off the east coast, USA. Proceedings of the Second International Conference on Transport, Fate and Effects of Silver in the Environment, University of Wisconsin-Madison, September 11-14, 1994, p. 61-68

Foxworth, R.D., 1962, Heavy minerals of sand from recent beaches of the Gulf coast of Mississippi and associated islands: Mississippi State Geological Survey Bulletin 93, 92p.

Lockwood, Millington, and McGregor, B.A., eds., 1988, Proceedings of the 1987 Exclusive Economic Zone Symposium on mapping and research: planning for the next 10 years: U.S. Geological Survey Circular 1018, 175 p.

Wynn, J.C., 1988, Titanium geophysics-- The application of induced polarization to sea floor mineral exploration: Geophysics, v. 53, p. 386-401.

Wynn, J.C., Grosz, A.E., and Foscz, V. M., 1990, Induced polarization and magnetic response of titanium- bearing placer deposits in the southeastern United States: Society of Exploration Geophysicists Special Volume on Induced Polarization, p. 280-303.

Wynn, Jeff, Kindinger, Jack, and Wiese, Dana, 1998, Experimental use of the induced polarization method to map and characterize the shallow sea-floor: Conference Proceedings, the Symposium for the Application of Geophysics to Environmental and Engineering Problems, held in Chicago, IL, 22-26 March 1998, pp. 781-784.

Wynn, Jeff, and Laurent, Kevin, 1998, A high-resolution electrical geophysical approach to mapping marine sediments in the Atlantic coastal shelf and the Gulf of Mexico: Proceedings Volume, Society of Exploration Geophysicists Annual International Meeting, New Orleans, LA 13-18 September, 1998, p. XXX-YYY.